SORGHUM SEED GERMINATION AS AFFECTED BY MOISTURE AND TEMPERATURE

by

WILBUR FELL EVANS

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INTRODUCTION

Since their introduction into the United States in 1853 (14), sorghums have assumed an ever increasing importance as a grain and forage crop due to their ability to grow in regions of limited rainfall and withstand extreme heat better than other crops. Sorghum's economic importance is best emphasized in that it is ranked second only to the production of wheat in the state of Kansas. The 1960 sorghum grain crop in Kansas is estimated at 149 million bushels by the United States Department of Agriculture (36).

For sorghum, as all other crops, the establishment of a vigorous uniform stand is prerequisite to production of a high yield of grain or forage. Fundamentally, such a stand depends on the use of high quality seed of known purity and germination. Seedbed preparation, seed treatment, rate and depth of planting, fertilization and other production practices are man controlled, and normally are expected to be of the highest quality that the grower can employ. Therefore, it is the response of the seed to its inherited characteristics, the vagaries of nature and production practices used that largely determines the success or failure of stand establishment.

The establishment of sorghum stands has often proved to be a considerable problem. In 1955 Ross and Laude (23) stated that "under good field conditions about two seeds must be sown for each plant that grows." Swanson and Hunter (33) indicated that discrepancies between laboratory and field germination of sorghum seed frequently ranged from 30-50 percent even when seed of high viability was used. Martin and Leonard (14) expressed the problem in this manner:

> In sorghum, a field emergence of 70 percent is exceptional, and 50 per cent emergence is all that is normally expected from seed having a 95 per cent laboratory germination, even in a good seedbed. However, if the seed germinates only 60 to 70 per cent in the laboratory, many of the sprouts will be so weakened that a field emergence of 20 to 25 per cent is all that can reasonably be expected.

The question, then, is what major factors affect the seed once it has been placed in the soil so that either germination and/or emergence does not occur. Many factors are known to influence emergence of sorghum seeds. Among these are attack of soil pathogens, improper temperatures, inadequate soil moisture, excessive soil moisture and related oxygen deficiency, or a low level of seed viability, such as described above by Martin.

Stand establishment of grain sorghum, although an expression of many factors, has been found to be closely influenced by soil moisture and temperature (33).

The present investigation was undertaken to determine possible varietal differences in grain sorghum for germination and seedling vigor under varying conditions of temperature and available moisture. The influence of temperature on germination of different lots of seed of the same variety was studied. It was also attempted to develop a system whereby varietal viability, as related to response in the field, could be tested under laboratory conditions. Finally, an investigation was instituted to determine if treatment of sorghum seed by gibberellic acid, a substance known to instigate growth or vigor in varied cases of application to plants, would appreciably affect viability or seedling vigor under limited moisture conditions.

REVIEW OF LITERATURE

In order that the literature reviewed might be presented in the most uniform and comprehensible manner, the principles concerning this work will be discussed in the following categories: Temperature, Moisture, Osmotic Tension Solutions, and Gibberellic Acid.

Temperature

Favorable temperature, oxygen supply, and optimum available moisture are generally considered the primary environmental requirements for seed germination (10). Should any one of these conditions not be met, germination will not occur, or will be reduced. Still, the permissible range for these requirements is quite broad.

Edwards (6) reviewed the literature accumulated from 1801 to 1932 on temperature relations and seed germination. He stated that most experimenters found the optimum temperature for seed germination of most crop plants usually fell between 20 and 30 degrees centigrade. The optimum temperature was near 35°C. for the germination of maize, rice, and soybeans. Edwards pointed out that optimum temperatures could vary according to the experimenters' definition of the term. However, high final germination percentage and rapidity of germination were normally the basis for defining optimum.

As cited by Edwards (6), numerous workers have established that the minimum temperature for germination is usually farther removed from the optimum than is the maximal temperature for germination. A notable example of this would be the germination obtained by Coffman (3) of winter wheat, rye, barley and alfalfa with the seeds practically

enclosed in ice.

The crops mentioned above are cool weather germinators but their temperature tolerances for germination differ considerably. Wilson (39) obtained regular decreases in germination percentage of wheat with each 5°C. rise in temperature above 15°C. while soybeans and oats responded equally well over the range of 10 to 30°C. This, of course, serves to illustrate differences in temperature tolerances between species.

Varietal variability can also be a factor in temperature tolerances for germination as shown by Veerhoff (37). When germinated at nine temperatures two varieties of flax grown under similar conditions gave entirely different responses. Both lots of seed were similar in giving highest germination percentage at the lowest temperature of 8°C., earliest production of seedlings at 31°C., and no germination at the highest temperature of 43°C. However, one variety gave successively lower germination percentages with higher temperatures, while the other variety showed high variability for all tested temperatures up to 34.5°C.

Temperature apparently affects seed germination of several crop plants in approximately the same manner, although these affects may take place at different temperatures. Haskell (8) determined germination of five inbred lines of sweet corn exposed to 40°F. and 50°F. after planting in soil flats. He found that germination decreased with an increase of duration in the cold temperatures. Part of the decrease was attributed to seed damage by the cold temperatures and part to soil pathogens attacking the weakened seedlings. Stitt (30) reported that germination of soybeans at low temperatures was slow, and resulted in a reduction of the number of emerged seedlings.

Robbins and Porter (21) exposed mature sorghum seeds containing 15 percent moisture or less to temperatures of from 33°F. to -20°F. They found these seeds were unaffected in germinability while in seeds with higher moisture content the germinability was reduced by exposure to low temperature. It would appear this phenomenon might be applicable to seeds that have imbibed water in the process of germination.

Martin *et al*.(15) planted four varieties of sorghum at three soil depths (1/2, 1 1/2, and 2 1/2 inches) and exposed them to five temperatures (15, 20, 25, 30, and 35°C.). They found decrease in the average germination percentage with temperatures below 25°C. Depth of planting did not affect germination except that a low germination percentage was noted from the deep planting at 15°C. Emergence was delayed by soil temperatures below 25°C. The time required for emergence increased from 4 days at 35°C to 9 and 11 days at 15°C.

Moisture

Moisture requirements for seed germination, like those of temperature, vary among species. Workers have found that not all seeds need the same amount of water to germinate and the ability of seeds to absorb water varies considerably.

Brown and Worley (2) studied the effect of temperature upon the rate of water absorption by barley seeds. Based on a theory of water molecule simplification by temperature, now discredited, they claimed

that the velocity of water absorption was almost an exponential function of the temperature. Shull (25) could not find support for this theory using Xanthium seed and pea cotyledons, but said the velocity of water intake at any given moment was approximately an inverse exponential function of the amount of water previously absorbed. This theory was further substantiated in tests with corn (26).

Stiles (29) tested the water absorption ability of three varieties of corn and three varieties of cotton. She found that seeds differed in the percentage of initial 24 hour water uptake and in the percentage of final (96 hours) water absorption. She concluded that there were varietal differences in the amount of germination water required.

Peters (18) worked on germination of seeds in a medium of low water content in an attempt to determine whether seeds can germinate when the amount of soil moisture present would not support growing plants. He found that seeds of peas, soybeans, corn and wheat germinated at or below the wilting coefficient of 1.31 percent moisture in quartz sand of 0.1 mm. size.

Hunter and Erikson (11) oven-dried five Michigan soils, remoistened them to moisture contents from permanent wilting percentage to field capacity, and sealed the soil in mason jars. Four kinds of seed (sugar beet, corn, soybean, rice) were then planted in the soils. They found that in order for the seeds to germinate, each species had to attain a specific moisture content. These minimum moisture contents for the seeds were approximately 30.5 percent for corn, 26.5 percent for rice, 50 percent for soybeans, and 31 percent for sugar beets. They also concluded that at 25°C., a soil should have a moisture

tension of not more than 12.5 atmospheres for corn kernels to germinate, 6.6 atmospheres for soybeans, and 3.5 atmospheres for sugar beets. Seeds planted in soil not sufficiently moist for germination were destroyed or damaged by soil fungi.

Similar methods were essentially employed by Doneen and MacGillivray (4) as they oven-dried two soil types and later rewet them using a cement mixer. Moisture ranges obtained included permanent wilting percentage and field capacity for each soil. Sealed in No. 2 friction top cans, the soils were planted to numerous varieties of vegetable seeds and germinated at constant temperatures. They found that germination was progressively delayed as the initial soil moisture was decreased, and that the germination percentage of lettuce, lima beans, and peas was lowered as the soil moisture was decreased toward the wilting percentage. For many crops, such as sweet corn, tomatoes, and squash, the proportion of seeds germinating was not influenced as long as the soil moisture was above the wilting percentage.

Working with soil salinity as well as soil moisture, Ayers (1) found that soil moisture stress at any given level increased with increased soil salinity and at any given level of soil salinity the moisture stress increased as the soil moisture decreased. These increased soil moisture stresses in turn were reflected in an increase in time required for emergence, a decrease in the percent of seeds which germinated, or both.

Smika and Smith (27), when studying the effect of biuret on the germination of wheat, observed germination of wheat even when the soil moisture content was near the wilting percentage.

Osmotic Tension

The use of salt or sugar solutions to create mediums of varying osmotic tensions for germination work, although not new, is becoming increasingly popular. The advantages of such solutions over the use of soil in ease and accuracy of preparation, and conservation of space, is clearly apparent. Evaporation of water from such solutions is not a serious problem as indicated by Uhvits (35), even when the solutions are contained in petri dishes. However, the possible toxicity of some solutions to seeds imposed restrictions as to the accuracy of germination results. Rudolfs (24) recognized this toxicity effect in his work with salt solutions.

Likewise, Uhvits (35) observed that although NaCl and mannitol solutions caused a reduction in both rate and total germination of alfalfa seeds as concentrations increased, a greater reduction of germination in NaCl solutions was apparently due to a toxic effect of the Na^+ or Cl^- ions.

Wiggans and Gardner (38) tested five different solutions (glucose, sucrose, D-mannitol, NaCl, and PVP—Polyvinylpyrrollidine, a long chain polymer), at varying concentrations in an attempt to find a chemical that could be used effectively for the control of moisture in nutrient cultures. Solutions of PVP and NaCl were apparently toxic to seed germination. Although the other three solutions gave satisfactory results, the glucose and sucrose solutions reduced germination considerably more at comparable concentrations than did the

mannitol. Actually, D-mannitol gave similar results at the 5 atmosphere level as the water checks, and 30 percent germination of sorghum was obtained at the 15 atmosphere level. Mannitol apparently affords a wider range of tensions for testing with no toxic effects than the other solutions. Thimann (34) stated that mannitol is the best available chemical to limit water uptake in a plant without affecting the metabolic action of the plant.

In comparing germination of sorghum varieties with known response to moisture conditions in the field, Wiggans and Gardner (38) concluded that at best osmotic solutions offer a test of physiological drouth resistance and perhaps than only in the seedling stage.

Helmerick and Pfeifer (9) tested Yogo and Cheyenne varieties of wheat in mannitol solutions with the objective of facilitating selection of wheat varieties with ability to germinate and grow under limited moisture conditions. They found that germination and growth of seedlings decreased as osmotic tension increased. However, Yogo gave significantly greater germination and growth than Cheyenne under both field and osmotic solution conditions. This would indicate that varietal responses to limited moisture conditions in the field might be evaluated under laboratory conditions.

Use of mannitol solutions to test drouth hardiness in several lines of Cheyenne wheat was reported by Powell and Pfeifer (19) to be a simple, easily-repeated test which gave a relative measure of differences among selections for drouth hardiness.

Rodger, et al. (22) found that as osmotic tension of the solutions

increased, speed and amount of germination of seed of several alfalfa varieties decreased. However, the decrease in germination was much more pronounced in the winter-hardy varieties than in non-hardy strains. Evidently, if osmotic solutions do offer feasible tests for seed and seedling hardiness characteristics, specification of the tests must be clearly defined for each species of seed.

Dotzenko and Dean (5) germinated six alfalfa varieties at moisture tensions of 7 and 12 atmospheres with mannitol along with water checks. They concluded that the ability to germinate at high osmotic pressures is heritable.

Gingrich and Russell (7) illustrated an important point that necessitates consideration when working with solutions of varying osmotic tension. When germinating kernels of corn in mannitol solutions and soil samples of corresponding tensions, they noted that although fresh weight and elongation of the seedlings decreased with increasing stresses in both media, dry weight decreased only in the soil. Radicle lengths obtained in the soil samples were shorter than those in mannitol solutions. They concluded that the water transmission characteristics of the soil, a factor not involved in osmotic tension solutions, were responsible for the differences.

Gibberellic Acid

Gibberellic acid is a chemical derivative of a group of plant growth substances known as gibberellins. These growth substances

were first shown to be produced by a rice disease fungus, Gibberella fujikuroi, from which their name was derived.

Stowe and Yamaki (32) in a review of gibberellin research traced the development of these substances. Stodola (31) and Marth et al. (13) also reviewed gibberellin work extensively. Some of the physiological effects noted have been increased cell elongation, increased cell division, adventitious root formation, and induced flowering. One of the most striking effects of gibberellic acid treatment has been the promotion of elongation in certain dwarf plants. Pauli and Sorenson (16) obtained such a result with dwarf alfalfa plants after gibberellic acid treatment, but found that these plants would not flower.

According to Stowe and Yamaki (32) gibberellic acid treatment of seeds has consistently reduced the time required for seed germination, but since final germination percentage was nearly complete in reported cases no effect on final germination could be discerned. Kasperbauer and Gardner (12) reported increased rate of emergence and temporarily increased growth of young sorghum plants following seed applications of gibberellic acid.

There is evidence that gibberellic acid may be able to substitute for red light in promoting lettuce germination (32).

In a series of laboratory and field tests, Pauli and Stickler (17) obtained accelerated rates of germination by Westland, Plainsman, and Redlan varieties of sorghum, particularly during the first 48 hours after gibberellic acid treatment. Final germination was not affected by any concentration of gibberellic acid. In the field,

treatment with gibberellic acid resulted in a faster emergence of seedlings, but final emergence was not affected.

MATERIALS AND METHODS

The techniques and materials employed in the experimental phase of this work are more easily described if considered separately. Therefore, the methods will be discussed under the topics: Soil Moisture and Temperature, Soil Temperature Effects on Different Seed Lots, Moisture Tensions by Mannitol Solutions, Gibberellic Acid Drought Test.

Soil Moisture and Temperature

Soil from the Northeast corner of the Agronomy Farm at Manhattan, Kansas, a poorly drained Alluvial silty clay loam (unnamed), was oven dried and its moisture constants determined. The moisture contents of the soil were determined as 24 percent water for field capacity and 11.1 percent water for permanent wilting percentage (coefficient). The method used was as described by Richards (20).

Using the same method as that described by Doneen and MacGillivray (4) the oven dried soil was remoistened to three desired moisture levels by spraying the soil with water as it was rotated in a cement mixer. The amount of water needed to be added to a certain quantity of soil to reach the required moisture level was calculated by the formula:

$$\frac{\text{Weight of Water}}{\text{Wt. Oven-dry soil}} \times 100 = \text{Desired \% } H_2O.$$

The three moisture levels obtained were field capacity (24%), a level slightly below the permanent wilting coefficient (9.8%), and an intermediate level (15.4%). The last two levels were arbitrarily chosen.

Once the soil had been brought to the desired moisture level, it was placed in one gallon containers (#10 tin cans) to a depth of 4-5 inches. The containers were immediately sealed by covering with a sheet of polyethylene plastic secured by heavy rubber bands to prevent water loss by evaporation. There were a total of 180 cans, 60 cans containing soil at field capacity, 60 and 15.4 percent moisture, and 60 at 9.8 percent moisture.

These cans were then separated into three different locations, there being 20 cans of each moisture level present at each location. Each can was then planted to one of ten varieties of sorghum, 25 seeds per can at a depth of 3/4 inch. Thus, at each location, one variety was planted to two replications of each moisture level. The ten sorghum varieties used were Black Amber, Blackhull Kafir, Dwarf Yellow Milo, Early Sumac, Ellis, Feterita, Martin, Midland, Reliance, and Westland.

The three locations in which the cans were placed represented the three temperature levels under which the seeds were to be germinated. The first location was the Agronomy greenhouse in which the cans were placed on tables. The temperature range for this location was the lowest range, 60-70° Farenheit. Since there was no thermostat or automatic temperature control apparatus, regulation of the temperature

was attempted by manual operation of overhead and side vents. Temperatures were recorded on a thermograph placed near the cans. Due to temperature changes, exact control was not possible and occasional fluctuations of ± 10°F beyond the desired range for short periods of time occurred.

The second location was the first floor of the temporary barracks located north of the greenhouse. The cans at this location were placed on tables. The desired temperature range for this location was 70-80°F. Control was by means of a thermostat which controlled the heat for the entire building. Temperature control at this location was adequate since the temperature rarely exceeded the limits of the desired range although varying without any particular pattern within the range. Temperatures were recorded by means of a recording thermograph.

The third location which supplied the high temperature range of 80-90°F., was the high temperature growth chamber located in the Plant Research Laboratory. At this location temperatures did not fluctuate in excess of ± 2°F. from the temperature setting of 88°F.

Since the entire experiment was conducted twice there was a total of four observations for each treatment combination. Cans were randomly arranged within observations within temperature levels. The first experiment was conducted in December, 1955, and the second experiment in March 1956.

All seeds were given a light application of Spergon for protection against fungi attack.

Readings were taken daily on the rate of emergence and the final reading considered to be total emergence.

Soil Temperature Effects on Different Seed Lots

In this phase of the study it was desired to determine temperature effects on germination of sorghum varieties exclusive of moisture effects. The importance of varietal variability as a factor in seed germination research was also investigated.

Ten separate lots of sorghum seed of each of Ellis, Martin, Midland, Early Sumac, and Westland sorghum were obtained from the Kansas Crop Improvement Association, Manhattan. The lots of seed were randomly selected from available certified supplies. Table 1 gives the identification number, germination percentage, date tested and source of each seed lot.

Wooden flats were filled with soil from the Agronomy Farm, with 20 rows per flat. Each lot of seed for a variety was planted to 2 rows in a flat, one flat thus contained two replications of each seed source for a given variety. Fifty seeds were sown per row, 3/4 of an inch in depth.

The flats were then allotted to three temperature locations, one flat of each variety (including different seed sources) to each location. These locations were the growth chamber of the Plant Research Laboratory for the high temperature range, 80-90°F., the temporary barracks for the medium temperature range, 70-80°F., and the refrigerated chambers in the Plant Research Laboratory for the cold temperature range, 60-70°F. Temperatures were recorded on thermographs at all locations. At all three temperatures control was maintained within the desired range.

Table 1. Identification number, germination percentage, date of germination test and source of seed lots of five sorghum varieties.

Variety	K.C.I.A. seed lot identification No.	Germination percentage	Date of germination test	Source county
Early Sumac	54-1227	89	11/16/54	Rawlins
	54-1611	93	1/ 4/55	Sheridan
	54-1599	87	1/ 4/55	Osborne
	54-1575	93	12/29/54	Smith
	54-1309	93	11/29/54	Gray
	54-1377	90	12/ 7/54	Kearny
	54-2069	90	2/14/55	Smith
	54-1971	92	4/22/55	Smith
	54-2515	85	4/22/55	Osborne
	54-1297	90*	—	—
Ellis	54-1205	83	11/29/54	Smith
	54-1301	89	11/26/54	Rush
	54-2371	91	3/21/55	Osborne
	54-2388	84	3/29/55	Trego
	54-1496	80	12/23/54	Smith
	54-1431	80	12/15/54	Osborne
	54-1770	88	1/17/55	Pawnee
	54-2392	94	3/ 8/55	Rush
	54-1472	86*	—	—
	54-1497	86*	—	—
Martin	54-2455	95	4/ 6/55	Rooks
	54-1385	90	12/ 7/54	Anderson
	54-2043	80	2/ 9/55	Osage
	54-1208	94	11/12/54	Lane
	54-2085	94	2/15/55	Thomas
	54-1321	94	11/21/54	Smith
	54-1410	93	12/ 9/54	Greeley
	54-2191	88	2/25/55	Stanton
	54-1196	92	11/ 6/54	Osborne
	54-1489	89	12/20/54	Russell
Midland	54-2496	93	4/13/55	Ellsworth
	54-1149	84	10/22/54	Barber
	54-1308	89	11/29/54	Republic
	54-1303	91	11/26/54	Cloud
	54-1409	93	12/ 9/54	Greeley
	54-1930	83	1/28/55	Osborne
	54-2540	85	5/ 2/55	Brown
	54-1782	89	1/19/55	Lyons
	54-2519	83	3/31/55	Jackson
	54-1931	83*	1/28/55	Osborne

Table 1 (cont.)

Variety	K.C.I.A. seed lot identification No.	Germination percentage	Date of germination test	Source county
Westland	54-2221	85	2/28/55	Rice
	54-2156	88	2/22/55	Atchison
	54-1561	94	12/28/54	Finney
	54-1337	96	11/30/54	Pratt
	54-2046	95	2/ 9/55	Finney
	54-1910	92	1/27/55	Rice
	54-1846	95	1/24/55	Phillips
	54-2105	90	2/17/55	Pratt
	54-1617	95	1/ 4/55	Edwards
	54-1607	90*	—	—

*Germination given is the mean of remaining lots of that variety. Official germination data were not available.

During the germination period the flats were watered as necessary to ensure favorable moisture conditions. Daily counts were taken on the rate of emergence and the final emergence count was considered to be total emergence. This experiment was conducted in June 1956.

Moisture Tension By Mannitol Solutions

To determine if differences existed between four varieties of sorghum (Midland, KS 602, RS 608, and RS 610) in their ability to germinate and grow under various moisture stresses, different osmotic tension solutions of mannitol were utilized. The four tensions employed were 0, 5, 10, and 15 atmospheres. The concentrations of mannitol, a hexahydric alcohol, per liter needed to produce these stresses were calculated by the following formula given by Wiggans and Gardner (38):

$g = \frac{PVm}{RT}$, where:

g = grams of solute (mannitol)

P = osmotic pressure

V = volume in liters

m = molecular weight of chemical used

R = .0825 atmospheres per degree per mole

T = absolute temperature

Since the osmotic tensions produced in this method were dependent upon constant absolute temperature, it was decided to conduct the experiment at 300° Absolute (27°C. or 80.6°F.). This temperature is within the range of 20-30°C., considered optimum for sorghum germination.

Germination was carried out in Petri dishes. Three 9 mm. filter papers were placed in each dish. Lots of 50 seeds each were counted out from each variety treated with Spergon, and placed in the Petri dishes. Each lot of seed was then covered with another filter paper. There were four replications of each treatment combination in a randomized block design.

Ten ml. of the four osmotic tension solutions were added to each dish.

The Petri dishes were then placed in a small growth chamber which afforded control within $\pm$ 2°F. of the desired temperature of 80°F. Although previous work had indicated evaporation was not a problem with osmotic solutions in Petri dishes, the dishes were covered with wet newspapers to deter any such action.

Germination counts were made daily and the final reading taken on the 6th day was considered to be total germination. A seed was considered to have germinated when both normal radicle and plumule were visible and distinct from the seed (about 1 mm. in length).

On the sixth day, measurements of the radicle length and plumule length of five seedlings from each Petri dish were taken as indication of growth.

Gibberellic Acid Drought Test

To evaluate effects of gibberellic acid treatment on sorghum seed germination and seedling vigor under varying moisture conditions,

mannitol and gibberellic acid solutions were made in order to obtain the desired concentrations of both solutes.

This was done by mixing the gibberellic acid solutions first, then adding mannitol in the necessary amounts to create the desired moisture stresses. Accordingly, 40, 80, and 120 mg. of 75 percent gibberellic acid, as prepared by Merck and Co., were dissolved in flasks each of which contained 500 ml. of tap water. These amounts created concentrations of 60, 120, and 180 parts per million gibberellic acid solutions, respectively. A fourth flask contained only water, which would serve as a check in the experiment. One hundred ml. of each of these solutions, including the water, were then transferred to each of four smaller flasks. Thus, there were 16 flasks, four flasks of each concentration of gibberellic acid solution.

To three of the four flasks of each concentration of gibberellic acid, and the water check, amounts of mannitol were added to create moisture tensions of 5, 10, and 15 atmospheres. The quantities of mannitol needed to reach these concentrations were calculated using the formula: $g = \frac{PVm}{RT}$, as described in the preceeding section. The concentrations of gibberellic acid were considered to be so slight that the osmotic pressure of the gibberellin acid was disregarded. Thus mannitol was added in the same amount as would be needed for pure water. There were, then, four concentrations each of gibberellic acid and mannitol moisture tensions, ranging from 0 atmospheres of tension and 0 ppm gibberellic acid to 15 atmospheres of tensions and 180 ppm gibberellic acid.

Glass Petri dishes were prepared by washing with a laboratory

detergent and air drying and three filter papers were placed in the dishes. Sixty-four lots of 50 seeds each of RS 608 grain sorghum were then placed in the Petri dishes. The seed had been treated with Spergon. Another filter paper was placed over the seeds. Ten ml. of each of the 16 solutions were then measured by pipette and placed in four Petri dishes. Each of the 16 treatment combinations were thus replicated four times in a randomized complete block design.

The temperature of the chamber was set at 80°F. in order to maintain the proper osmotic tensions as calculated by formula. Temperature in the growth chamber did not vary more than ± 2°F. from 80°F. during the germination period. Wet newspapers were placed over the Petri dishes to ensure evaporation of water from solutions would not be a problem. No growth of fungi was observed in the dishes.

Daily counts were made on the germination rate of the seeds. Germination of the seeds was considered to have occurred when both the radicle and plumule were separate and distinct from the seed (approximately 1 mm. in length). Germination was complete on the sixth day from the start of the experiment and final germination counts taken. Also, measurement of the length of the radicle and plumule of five seedlings from each Petri dish was taken as a measure of growth.

All data obtained from the different experiments were analyzed statistically according to procedures outlined by Snedecor (28).

EXPERIMENTAL RESULTS AND DISCUSSION

The experimental results will be discussed in four sections in

order that the influence of temperature and moisture on sorghum germination and seedling growth can be more clearly presented.

Part I - Soil Moisture and Temperature

This experiment dealt with the rate and extent of sorghum emergence as influenced by: variety, moisture, availability, temperature.

Variety. The ten sorghum varieties included in this experiment, their laboratory tested germination percentage, and total germination (emergence) percentage at three soil moisture stresses and three temperatures are presented in Table 2. Tested germination percentage of the varieties ranged from 62.5 to 97.5 percent.

Germination (emergence) in any of the varieties was not observed at the lowest moisture content of 9.8 percent, which was slightly below the permanent wilting coefficient of 11.1 percent. Total emergence of individual varieties among temperature treatments appeared to be fairly uniform, although the lowest temperature reduced emergence as did the medium temperature to a lesser degree.

Differences in total emergence among the ten varieties were significant at the 1 percent level (Table 3). However, this is of limited meaning in view of the wide range in tested germination percentage of the varieties. An array of the variety means of total emergence at all treatment combinations failed to reveal any varietal trends of response to the varied moisture and temperature treatments. The least significant difference (LSD) for comparing treatment means is included in Table 2.

Table 2. Total germination (emergence) percentage of ten sorghum varieties at three moisture stresses and three temperatures.

Variety	Laboratory germ.	Soil moisture	Temperature ranges (°F.) 60-70	70-80	80-90
Black Amber	97.5%	9.8%	0%	0%	0%
		15.4	88	100	95
		24.0	96	93	97
Blackhull Kafir	62.5	9.8	0	0	0
		15.4	74	74	59
		24.0	84	96	97
Dwarf Yellow Milo	89.0	9.8	0	0	0
		15.4	63	76	91
		24.0	84	80	90
Early Sumac	94.0	9.8	0	0	0
		15.4	66	59	55
		24.0	96	91	94
Ellis	76.0	9.8	0	0	0
		15.4	82	85	91
		24.0	85	92	79
Feterita	87.0	9.8	0	0	0
		15.4	75	76	75
		24.0	81	76	84
Martin	81.0	9.8	0	0	0
		15.4	75	72	75
		24.0	75	80	87
Midland	97.0	9.8	0	0	0
		15.4	79	76	67
		24.0	96	96	99
Reliance	85.0	9.8	0	0	0
		15.4	73	77	77
		24.0	93	89	92
Westland	82.5	9.8	0	0	0
		15.4	69	93	83
		24.0	92	93	91
LSD, .05 level					14.6

Table 3. Analysis of variance of percent emergence of ten sorghum varieties at two moisture stresses and three temperatures.

Source of Variation	df	Mean Square
Total	239	
Experiments	1	4,437.6**
Temperature	2	374.6*
Moisture	1	12,212.2**
Variety	9	918.1**
Temperature x variety	18	189.2/
Moisture x variety	9	767.8**
Moisture x temperature	2	268.5/
Experiment interactions	12	715.8**
Temperature x variety x moisture	18	728.0**
Sampling error	120	100.5
Error	47	106.6

** Significant at 1 percent level.
* Significant at 5 percent level.
/ Significant at 10 percent level.

<u>Moisture Availability</u>. Analysis of variance of total emergence of ten sorghum varieties at three temperatures and two moisture stresses is presented in Table 3. The failure of any variety to emerge from soil at 9.8 percent moisture (slightly below the wilting point) precluded the inclusion of the results at that moisture stress in the analysis of variance.

The differences in total emergence at the two moisture stresses and the moisture x variety interaction were significant at the 1 percent level of probability. Differences in percent emergence between the moisture stresses for all varieties at all three temperatures are, with few exceptions, clearly discernible, the medium soil moisture level resulting in a lower emergence percentage. The only instances where this

trend was reversed was with Black Amber at the medium temperature and Dwarf Yellow Milo and Ellis at the higher temperature. In these three cases, a higher percent emergence was obtained from the medium soil moisture treatment.

Total emergence was similar for the high and medium soil moisture stresses regardless of temperature treatment.

Temperature. The rate of emergence of the ten sorghum varieties at the two moisture stresses and three temperatures is included as Table 4. A summarization of this table giving the rate of emergence of the ten varieties averaged together for each moisture-temperature combination is presented graphically in Figure 1.

Differences in total emergence percent obtained from the three temperatures were significant at the 5 percent level, the lower temperatures resulting in a lower emergence.

Figure 1 illustrates that at the high temperature of 80-90°F. emergence was essentially complete at six days. Emergence at the two lower temperatures took successively longer periods of time to be completed. This ranged from seven days for seeds in the high moisture soil at the medium temperature, to ten days for seeds in the medium moisture soil at the medium temperature and both soil moisture stresses at the low temperature.

The different rates of emergence at the various moisture and temperature levels are clearly shown in Figure 1. The faster emergence is reflected by lines hyperbolic in form, the slower rate of emergence at the low temperature by lines parabolic in form. The lines representing emergence at the medium temperature trace paths roughly between the

Table 4. Rate of emergence of ten sorghum varieties at two moisture stresses and three temperatures.

Variety	Temperature °F	Percent Soil Moisture	3	4	5	6	7	8	9	10
			Days							
Black Amber	60-70	15.4	0	3	3	19	28	43	73	88
		24.0	0	15	22	39	57	71	90	96
	70-80	15.4	1	34	54	76	94	97	98	100
		24.0	6	40	58	84	92	92	92	93
	80-90	15.4	21	81	92	94	95			
		24.0	14	89	97					
Blackhull Kafir	60-70	15.4	0	1	2	9	16	31	58	74
		24.0	0	23	35	46	57	65	73	84
	70-80	15.4	0	11	21	31	42	54	63	74
		24.0	16	48	90	94	95	96		
	80-90	15.4	14	33	43	52	59			
		24.0	43	96	97					
Dwarf Yellow Milo	60-70	15.4	0	25	27	28	47	55	60	63
		24.0	0	33	35	42	76	77	80	84
	70-80	15.4	19	58	58	61	65	68	70	76
		24.0	25	51	72	77	78	78	80	80
	80-90	15.4	46	83	89	90	91			
		24.0	41	86	90					
Early Sumac	60-70	15.4	0	2	4	10	22	29	39	66
		24.0	0	32	34	40	60	75	88	96
	70-80	15.4	3	38	47	54	55	55	57	59
		24.0	26	52	76	88	91			
	80-90	15.4	19	46	54	55				
		24.0	34	81	91	94				
Ellis	60-70	15.4	0	11	19	30	50	55	69	82
		24.0	0	34	41	46	62	69	81	85
	70-80	15.4	11	32	47	66	71	82	84	85
		24.0	25	44	68	83	88	92		
	80-90	15.4	23	80	89	90	91			
		24.0	20	76	79					

Table 4 (cont.)

Variety	Temperature °F	Percent Soil Moisture	Days 3	4	5	6	7	8	9	10
Feterita	60-70	15.4	0	12	16	22	55	59	66	75
		24.0	0	25	30	38	50	69	75	81
	70-80	15.4	9	35	48	55	61	67	71	76
		24.0	18	33	64	73	75	76		
	80-90	15.4	14	44	64	69	75			
		24.0	33	77	84					
Martin	60-70	15.4	0	1	2	5	8	13	21	45
		24.0	0	2	14	23	32	43	63	75
	70-80	15.4	0	4	14	23	41	64	68	72
		24.0	0	8	33	70	78	80		
	80-90	15.4	2	27	60	68	75			
		24.0	26	78	86	87				
Midland	60-70	15.4	0	0	0	1	3	15	61	79
		24.0	0	1	8	31	48	55	89	96
	70-80	15.4	0	19	38	41	48	56	68	76
		24.0	5	48	52	91	95	96		
	80-90	15.4	8	45	66	67				
		24.0	41	96	99					
Reliance	60-70	15.4	0	9	11	17	27	36	42	73
		24.0	0	17	24	27	52	65	89	93
	70-80	15.4	14	36	46	54	60	62	71	77
		24.0	33	50	65	77	85	89		
	80-90	15.4	23	60	76	76	77			
		24.0	29	77	92					
Westland	60-70	15.4	0	7	10	16	32	43	54	69
		24.0	0	19	32	39	61	71	82	92
	70-80	15.4	10	33	53	58	67	69	82	83
		24.0	19	46	76	89	92	92	92	93
	80-90	15.4	26	54	61	77	83			
		24.0	41	83	90	91				

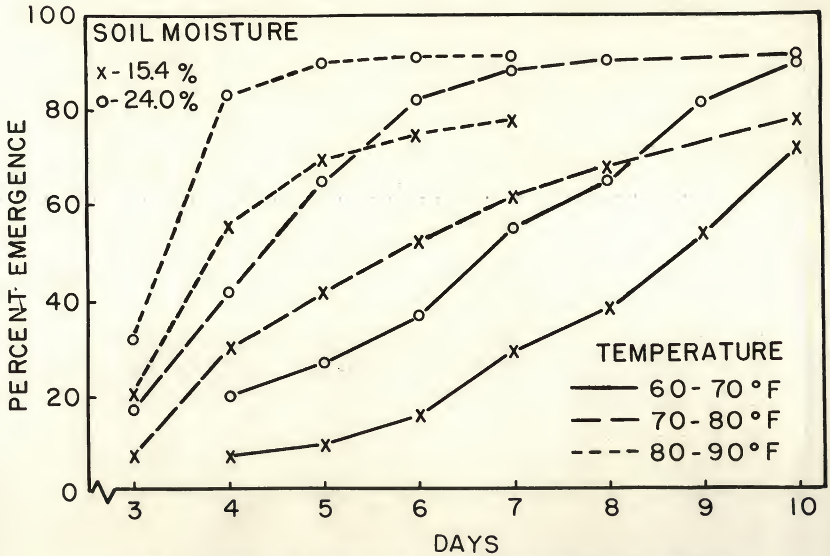

Figure 1. Average rate of emergence of ten sorghum varieties at two moisture tensions and three temperatures.

two types, although seeds at the higher moisture in this temperature approach the high temperature emergence rate. This delayed emergence at soil temperatures below 25°C. is in agreement with the results of Martin et al. (15).

The average total emergence approached the same values of 75 percent and 89 percent for the low and high soil moisture regardless of the temperature treatment.

Analysis of variance showed the difference between experiments to be significant at the 5 percent level. This difference is considered to be due mainly to temperature effects, as temperature controls constituted a major problem in this study.

Part II - Effect of Temperature on Germination of Different Seed Lots

The effect of temperature upon the emergence of different seed lots was so apparent that statistical analysis between temperature treatments was not undertaken. However, analysis of the data within temperatures expressed as the percent of official germination of the seed lots is presented in the sections: high temperature, medium temperature and low temperature.

High temperature. The analysis of variance of the total emergence of the ten seed lots for each of five sorghum varieties at 80-90°F. as a percent of official germination is presented in Table 5.

The differences in total emergence between the five varieties were significant at the 1 percent level, as were the differences between the ten seed lots within each variety.

Table 5. Analysis of variance of total emergence of ten seed lots of each of five sorghum varieties at 80-90°F.

Source of Variation	df	Mean Square
Total	99	
Variety	4	4,313.5**
Lots within varieties	45	380.3**
Error	50	100.8

** Significant at 1 percent level.

The average final emergence of the five varieties ranged from 30.4 percent of Ellis to 68.7 percent of Martin. The other varieties in order of total emergence were Early Sumac, 52.5 percent; Midland, 54.8 percent; and Westland, 67.4 percent. Within varieties, the differences in total emergence between seed lots ranged from 32 percent in Martin to 57 percent in Midland, the other differences within varieties being 37 percent for Ellis, 34 percent for Early Sumac, and 47 percent for Westland. The rate of emergence for each of these seed lots within varieties is reported in Table 6. The variability in germination rates among these varieties is more evident when the data are presented graphically. Figure 2 shows the rate of emergence of the five sorghum varieties. Martin and Westland exhibited a very low emergence on the second day compared to that reached on the third day, while Early Sumac had a relatively high emergence on the second day when compared to its total emergence. Common to all varieties was the near completion of emergence by the third day.

Table 6. Rate of emergence by days of ten seed lots of five sorghum varieties at 80-90°F.

Variety	Seed lot number	Days			
		2	3	4	5
Ellis	1	2	23	28	28
	2	5	35	36	36
	3	0	17	21	22
	4	1	19	25	25
	5	3	39	46	46
	6	6	30	33	34
	7	0	5	9	9
	8	4	24	28	28
	9	5	34	38	38
	10	2	31	37	38
Martin	1	1	72	73	73
	2	0	47	49	51
	3	3	59	69	71
	4	0	66	70	71
	5	0	66	77	77
	6	3	63	67	67
	7	1	67	71	71
	8	2	63	72	72
	9	4	78	82	83
	10	0	43	48	51
Midland	1	28	91	92	92
	2	5	37	43	43
	3	1	34	40	40
	4	13	60	62	62
	5	10	39	47	49
	6	10	30	35	35
	7	11	62	65	65
	8	9	49	55	56
	9	3	61	68	69
	10	6	35	37	37
Early Sumac	1	40	47	47	47
	2	24	43	46	46
	3	29	42	45	45
	4	28	52	52	52
	5	30	54	54	54
	6	36	59	64	65
	7	20	33	34	34
	8	38	54	54	54
	9	47	58	60	60
	10	46	59	68	68

Table 6 (cont.)

Variety	Seed lot number	Days 2	3	4	5
Westland	1	13	64	66	67
	2	14	69	73	74
	3	40	85	88	89
	4	10	60	61	63
	5	6	53	59	60
	6	8	56	58	61
	7	12	80	80	80
	8	8	64	67	67
	9	4	39	42	42
	10	12	62	71	71

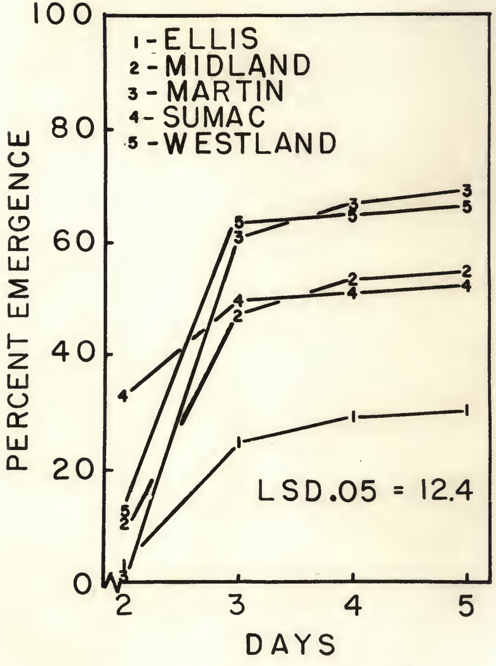

Figure 2. Rate of emergence of five sorghum varieties at 80-90°F.

To illustrate the variability in emergence among seed lots, the rate of emergence of the ten seed lots of Midland sorghum is presented in Figure 3.

Medium temperature. The rate of emergence of the ten seed lots for each of five varieties at 70-80°F. is reported in Table 7 and summarized graphically by varieties in Figure 4. At 70-80°F., total emergence was reduced for all varieties while time to achieve total emergence was extended by as much as three days compared with the higher temperature of 80-90°F. Midland again displayed the greatest variability between seed lots. Also the differences between the lots of highest and lowest emergence percent increased for Martin, Midland, and Westland at this temperature. The variability of seed lots within Midland at this temperature is illustrated in Figure 5.

Emergence of Ellis was drastically reduced at this temperature and that of Early Sumac was considerably lowered.

Low Temperature. The rate of emergence of the ten seed lots for each of the five varieties at 60-70°F. is reported in Table 9.

Generally, there was no emergence at this temperature. The highest emergence percentage obtained was 11 percent by one seed lot each in Westland and Martin. There was no emergence of Ellis and most of the seed lots of Midland and Early Sumac showed only 1 or 2 percent emergence after 26 days.

Analysis of variance of the total emergence percentage of ten seed lots in each of the five varieties at the low temperature is presented in Table 10. The differences in total emergence among varieties

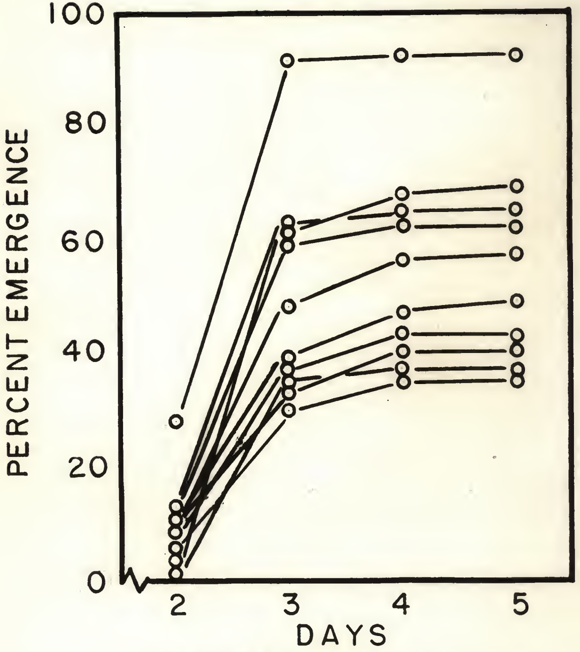

Figure 3. Rate of emergence of ten seed lots of Midland grain sorghum at 80-90°F.

Table 7. Rate of emergence by days of ten seed lots of five sorghum varieties at 70-80°F.

Variety	Seed lot No.	Days 2	3	4	5	6	7	8
Ellis	1	0	0	8	9	10	10	10
	2	0	0	1	2	3	4	4
	3	0	0	1	1	2	2	2
	4	0	0	2	3	4	4	4
	5	0	0	7	10	12	13	13
	6	0	0	0	0	0	0	0
	7	0	0	0	0	0	0	1
	8	0	0	4	6	6	6	6
	9	0	0	6	6	7	7	7
	10	0	0	6	6	6	6	6
Martin	1	0	11	23	36	69	71	71
	2	0	7	22	27	27	29	30
	3	0	17	34	38	39	42	42
	4	0	15	37	52	54	54	56
	5	0	14	47	73	79	80	81
	6	0	26	43	52	52	52	52
	7	0	12	22	42	53	53	53
	8	0	17	31	49	62	67	67
	9	0	17	40	56	66	67	67
	10	0	15	27	30	33	34	34
Midland	1	0	52	71	74	—	75	
	2	0	2	6	6	—	6	
	3	0	0	13	15	—	16	
	4	0	21	43	49	—	49	
	5	0	7	23	26	—	27	
	6	0	1	6	9	—	9	
	7	0	19	37	42	—	45	
	8	0	2	10	14	—	15	
	9	0	9	23	41	—	42	
	10	0	2	4	7	—	8	
Early Sumac	1	13	26	31	31	—	31	
	2	7	20	22	23	—	23	
	3	5	20	25	25	—	25	
	4	1	36	43	45	—	47	
	5	1	41	44	44	—	44	
	6	5	23	32	32	—	33	
	7	6	33	37	38	—	40	
	8	10	38	39	39	—	39	
	9	17	47	49	50	—	50	
	10	3	33	39	40	—	40	

Table 7 (cont.)

Variety	Seed lot No.	Days						
		2	3	4	5	6	7	8
Westland	1	0	47	55	58	58	58	58
	2	0	37	50	51	51	53	53
	3	0	69	83	87	87	87	87
	4	0	52	60	65	65	66	66
	5	0	30	35	37	37	37	37
	6	0	49	53	53	53	54	54
	7	0	40	45	48	49	49	49
	8	0	47	56	60	61	61	61
	9	0	33	38	43	43	43	43
	10	0	45	50	54	56	56	56

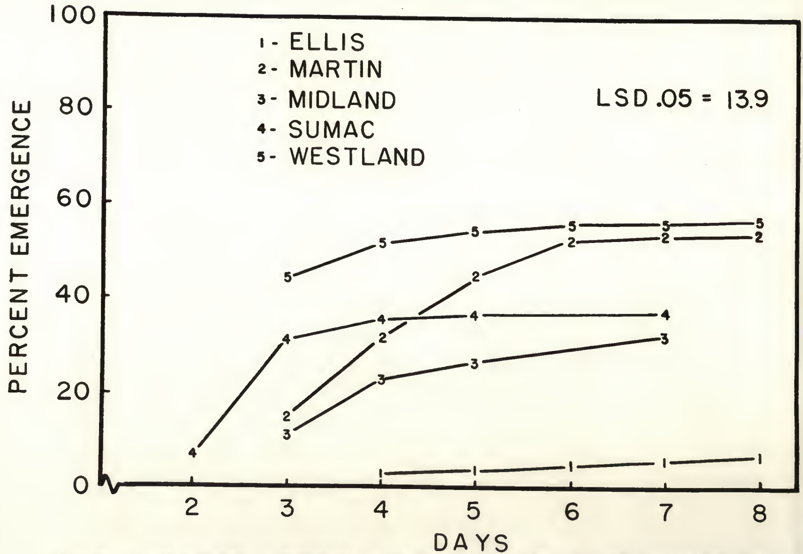

Figure 4. Average rate of emergence of ten seed lots for each of five varieties at 70–80°F.

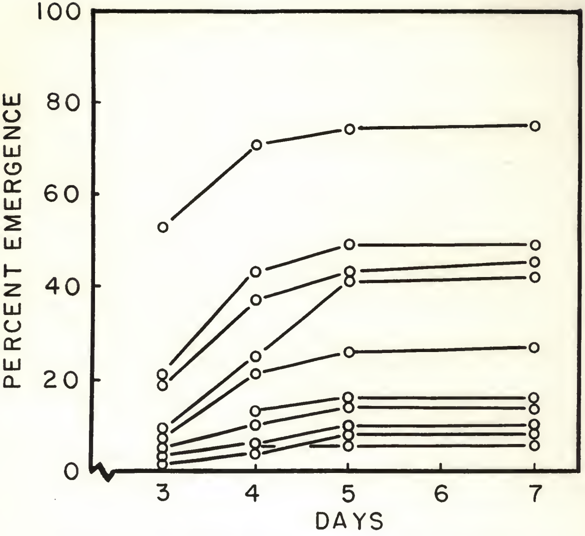

Figure 5. Rate of emergence of ten seed lots of Midland grain sorghum at 70-80°F.

Table 8. Analysis of variance of total emergence of ten seed lots of five varieties at 70-80°F.

Source of Variation	df	Mean Square
Total	99	
Varieties	4	10,566.8**
Lots within varieties	45	477.5**
Error	50	135.5

** Significant at 1 percent level.

were significant at the 1 percent level of probability. Thus, the varieties responded differently to the low temperature, the greatest differences being 11 percent which was the highest emergence obtained by any variety seed lot. Seed lots within varieties did not show significant variability, but this was probably due to the overall low germination at this temperature. No variability was possible in Ellis, for instance, as all seed lots failed to germinate.

Another aspect of the variability of seed lots within a variety is presented graphically in Figures 6 and 7. These graphs show that although the seed lots within Midland and Westland varieties varied in total emergence at any one temperature, the seed lots also gave varied responses between temperatures. For example, a seed lot that ranked sixth in total emergence at 70-80°F. ranked second in total emergence at 80-90°F. This variability of seed lots between temperatures, plus the variability of seed lots at any one temperature would indicate that no one lot of seed could be confidently considered as representative of any one variety.

Table 9. Rate of emergence by days of ten seed lots of five sorghum varieties at 60-70°F.

Variety	Seed lot No.	Days 8	9	10	14	26
Ellis	1-10	0	0	0	0	0
Martin	1	2	2	2	2	4
	2	0	0	0	0	0
	3	2	2	4	4	5
	4	0	0	0	0	0
	5	4	6	8	9	11
	6	0	1	2	3	4
	7	0	0	0	0	0
	8	0	1	1	2	3
	9	0	0	0	2	2
	10	0	0	1	1	1
Midland	1	3	3	3	4	4
	2	0	0	0	0	1
	3	0	0	0	1	1
	4	1	1	1	1	1
	5	0	0	0	1	1
	6	0	0	1	1	1
	7	0	0	1	1	1
	8	0	1	1	1	1
	9	4	7	7	9	9
	10	0	0	0	0	0
Early Sumac	1	0	0	0	0	0
	2	5	5	5	6	6
	3	0	0	1	1	1
	4	1	1	2	2	2
	5	1	1	1	1	1
	6	2	2	2	2	2
	7	0	0	0	0	1
	8	0	0	0	0	0
	9	1	1	1	1	1
	10	10	10	10	10	10
Westland	1	4	4	4	5	7
	2	1	1	2	2	2
	3	9	10	11	11	11
	4	0	0	0	0	0
	5	0	0	0	1	1
	6	0	0	0	0	0
	7	3	3	3	3	3
	8	1	1	1	2	2
	9	0	0	0	0	0
	10	0	0	0	0	0

In general, decreasing temperatures resulted in decreasing total emergence with practically no emergence occurring at 60-70°F.

Table 10. Analysis of variance of total emergence of ten seed lots of five sorghum varieties at 60-70°F.

Source of Variation	df	Mean Square
Total	99	
Varieties	4	30.2**
Lots within varieties	45	19.3**
Error	50	7.0

**Significant at 1 percent level.

Part III - Osmotic Tension by Mannitol Solutions

This experiment was conducted with four grain sorghum varieties to determine the influence of moisture tension on: rate of germination, total germination, and seedling growth.

Rate of Germination. The rate of germination of four sorghum varieties at four moisture stresses by days is reported in Table 11, and summarized graphically in Figure 8. Germination at the two lower moisture stresses, 0 and 5 atmospheres, progressed rapidly and was essentially complete by the third day. Germination at the two higher tensions was extended beyond this time, and was not complete until the sixth day. This retardation of germination by higher moisture tension was evident in the number of seeds germinated on the first day. A substantially higher percentage of seeds had germinated in the 0

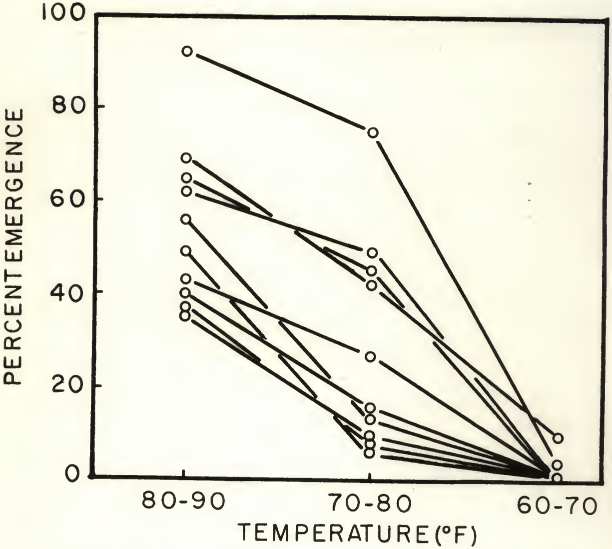

Figure 6. Total emergence of ten seed lots of Midland grain sorghum at three temperatures.

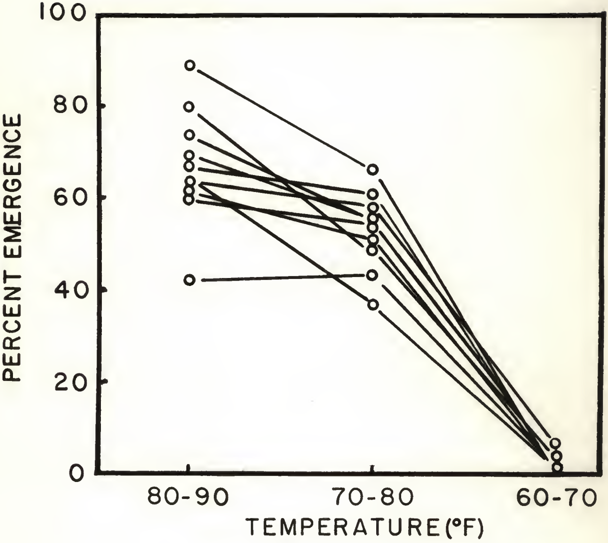

Figure 7. Total emergence of ten seed lots of Westland grain sorghum at three temperatures.

Table 11. Rate of germination by days of four sorghum varieties at four moisture tensions.

Variety	Moisture tension Atmospheres	Days 1	2	3	4	5	6
Midland	0	24	86	90	90	91	91
	5	10	86	90	92	94	94
	10	0	52	80	86	88	88
	15	0	12	42	68	76	81
KS 602	0	66	94	96	96	96	96
	5	18	90	92	95	95	95
	10	7	64	88	92	95	95
	15	0	24	50	60	65	70
RS 608	0	35	86	88	89	90	90
	5	10	70	83	85	86	87
	10	0	27	51	64	73	79
	15	0	13	28	41	50	63
RS 610	0	4	87	91	95	95	95
	5	0	45	80	87	88	90
	10	0	18	37	48	52	53
	15	0	8	19	29	31	31
LSD, .05 level							10.8

atmosphere tension solution (water) than at the 5 or 10 atmosphere tensions. Germination of seeds at 15 atmospheres was not observed until the second day. The percentage of seeds germinated at five atmospheres of tension increased rapidly after the first day and then gradually increased to the final percentage as did the seeds in the water solution. Germination of seeds at 10 and 15 atmospheres was characterized by a slow gradual rise to total germination.

Total Germination. Total germination of the four sorghum varieties progressively decreased as moisture tensions increased. Analysis of

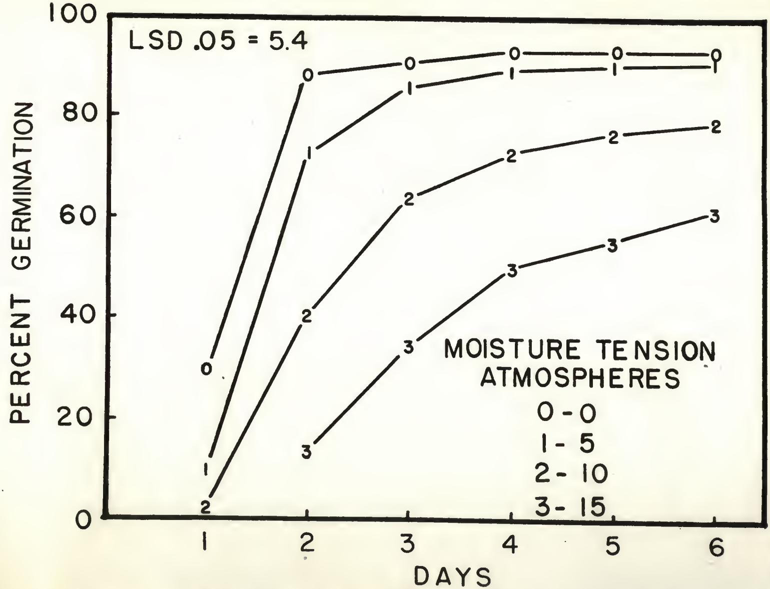

Figure 8. Average germination of four grain sorghum varieties at four moisture tensions.

variance of the total germination percentages of the four sorghum varieties at four moisture tensions as a percent of germination at 0 atmospheres is presented in Table 12.

The differences in total germination between varieties and moisture tensions were significant at the 1 percent level. The interaction of varieties and moisture tension was also significant at the 1 percent level indicating that the varieties responded differently to the moisture tensions as shown in Table 11. Midland and KS 602 exhibited more uniform germination at the three higher moisture stresses with Midland germinating significantly better at 15 atmospheres of tension than the other varieties. RS 610 gave the poorest response of the varieties at the 5, 10, and 15 atmospheres of tension.

Final germination at 5 atmospheres of tension approached the same percentage as that of the water checks.

Seedling growth. Seedling growth of the four varieties at four moisture tensions was estimated by averaging the length of the radicle and the length of the plumule of five seedlings of each treatment combination in each replication. Analysis of variance of the average plumule and radicle lengths is presented in Table 13.

The differences between varieties for both plumule and radicle growth were significant at the 5 percent level and differences among moisture tensions were significant at the 1 percent level. The interaction of variety and moisture tension for both radicle and plumule development was significant at the 1 percent level. Figure 9 shows the average plumule and radicle lengths of the four varieties at

Table 12. Analysis of variance of total germination of four grain sorghum varieties germinated at four moisture tensions.

Source of Variation	df	Mean Square
Total	63	
Replications	3	29.43
Variety	3	2,137.18**
Moisture tension	3	3,942.51**
Variety x moisture	9	594.15**
Error	45	57.58

** Significant at 1 percent level.

Table 13. Analysis of variance of mean plumule and mean radicle lengths of four grain sorghum varieties germinated at four moisture tensions.

Source of Variation	df	Mean Squares	
		Plumules	Radicles
Total	63		
Replications	3	0.045	0.023
Variety	3	0.505*	0.952*
Moisture tension	3	34.012**	465.865**
Variety x Moisture	9	0.408**	0.795**
Error	45	0.122	0.229

* Significant at 5 percent level.
** Significant at 1 percent level.

the four moisture stresses. Tension effects are easily discernible, there being progressive decreases in the amount of growth as moisture tensions increased. Although 5 atmospheres of tension reduced the lengths of the radicles and plumules, the most drastic reductions in

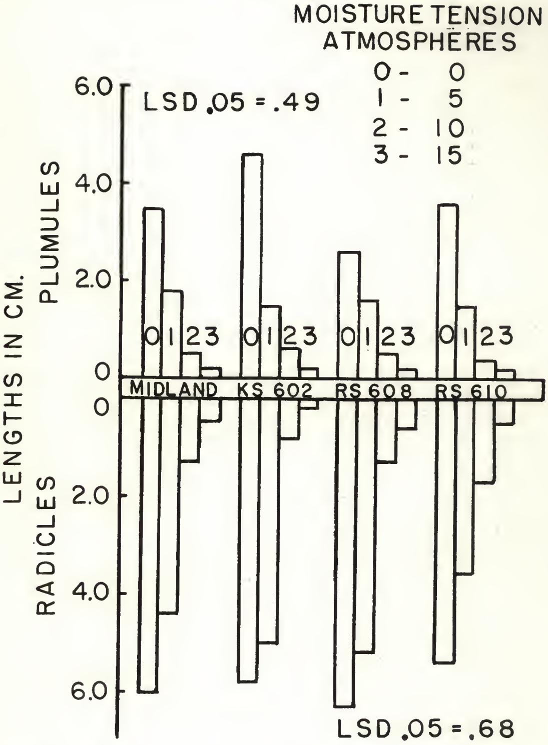

Figure 9. Average plumule and radicle lengths of four grain sorghum varieties germinated at four moisture tensions.

size occurred at 10 and 15 atmospheres. RS 608 attained the greatest radicle length at 0 and 5 atmospheres but had a shorter growth of plumule than the other varieties. RS 610 gave the most uniform response to increasing moisture tensions, the decreases in radicle length being almost a straight-line relationship with the increasing tensions. Under field conditions the seedling vigor of RS 608 and RS 610 has been considered to be superior to that of KS 602 or Midland.[1/] It is possible this differential in vigor might be discernible only at a later stage of growth. Under normal conditions in the field, six day old seedlings would have barely emerged. The possibility exists then, that a comparison for vigor should be made on older plants.

Although all the varieties managed to germinate and grow to a certain extent at the higher moisture tensions, the dehydrated and burned appearance of the seedlings indicated that such growth probably could not be sustained under these limited moisture conditions.

Part IV - Gibberellic Acid-Drought Test

Germination of grain sorghum under varying moisture stresses and levels of gibberellic acid was studied to determine the influence of Gibberellic acid on: rate of germination, total germination, and seedling growth under different levels of simulated drought.

Rate of Germination. The rate of germination of RS 608 sorghum

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[1/] C. B. Overly. Personal communication with author, Dec. 2, 1960.

at four moisture stresses and four gibberellic acid treatments is reported in Table 14 and illustrated at two moisture stresses in Figure 10. There was a progressively greater percentage of germination on the first day at 0 atmospheres of tension as the concentration of gibberellic acid increased. The range of germination percentage between gibberellic acid concentrations had decreased considerably by the second day as all treatments at this moisture tension attained near maximum germination. The difference between the high and low germination percentages at this moisture tension dropped from 22 percent on the first day to only 4 percent on the second day. Notable also on the second day was that the germination percentage attained with the lower concentrations of gibberellic acid were greater than the germination at the higher concentrations, indicating possible toxicity.

At the high moisture tension of 15 atmospheres, there was no germination on the first day. However, germination which occurred on the second day again increased as gibberellic acid concentration increased, with the exception of a lower percent germination at 180 ppm. gibberellic acid than at 120 ppm. gibberellic acid. After the third day, percent germination achieved by the seeds in the higher concentrations of gibberellic acid progressively increased over the percent germination of seeds in the tension solution with no gibberellic acid treatment.

Total germination. Analysis of variance for total germination and mean plumule and mean radicle lengths of RS 608 sorghum under four moisture tensions and four concentrations of gibberellic acid is reported in Table 15.

Table 14. Rate of germination by days of RS 608 sorghum at four moisture tensions and four gibberellic acid concentrations

Moisture tension (Atmos.)	Gibberellic acid (ppm.)	Days					
		1	2	3	4	5	6
0	0	19	79	83	86	86	86
	60	30	81	83	84	86	86
	120	33	83	88	88	89	89
	180	41	80	85	85	85	86
5	0	6	79	83	85	86	88
	60	6	63	75	80	81	82
	120	8	80	83	85	85	86
	180	9	78	84	87	87	87
10	0	0	55	76	81	84	86
	60	0	49	74	80	81	82
	120	0	46	70	78	82	83
	180	0	57	76	83	84	86
15	0	0	14	38	47	58	63
	60	0	20	43	54	65	73
	120	0	26	47	57	68	76
	180	0	21	48	61	73	81
LSD, .05 level							9

Differences in germination as affected by osmotic tensions were significant at the 1 percent level of probability. Figure 10 illustrates the much lower germination percentage attained by the seeds germinated in the high osmotic tension of 15 atmospheres as compared with the seeds germinated at 0 atmospheres of tension. The differences in total germination among concentrations of gibberellic acid were significant at the 25 percent level, suggesting that gibberellic acid did not have a strong effect on total germination. At the higher concentrations of

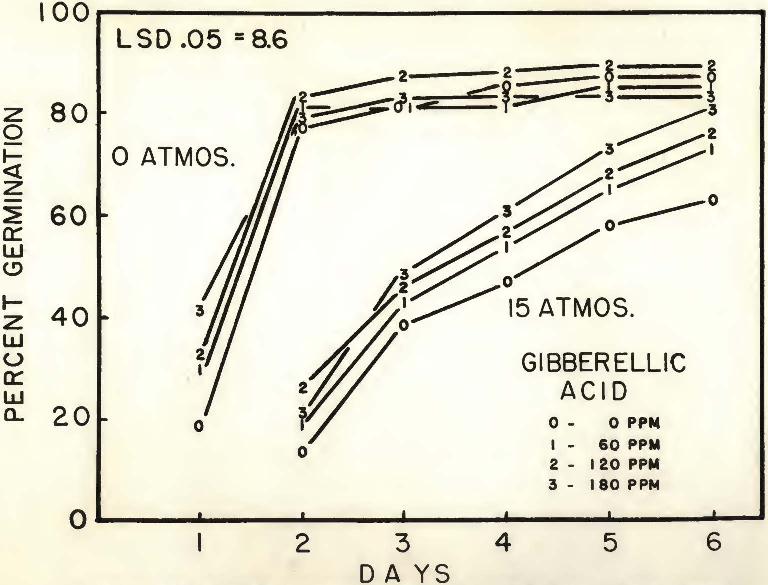

Figure 10. Rate of germination of RS 608 grain sorghum at 0 and 15 atmospheres of moisture tension and four gibberellic acid concentrations.

Table 15. Analysis of variance of total germination and mean plumule and mean radicle lengths of RS 608 sorghum at four moisture tensions and four concentrations of gibberellic acid.

Source of Variation	df	Mean Squares: Total germination	Plumules	Radicles
Total	63			
Replications	3	32.416	0.122	0.303
Moisture tension	3	616.916**	49.342**	117.116**
Gibberellic Acid	3	70.416#	2.022**	0.1885
Tension x Gibberellic Acid	9	72.194/	0.389*	0.232
Error	45	36.505	0.172	0.535

\# Significant at 25 percent level.
/ Significant at 10 percent level.
* Significant at 5 percent level.
** Significant at 1 percent level.

120 and 180 ppm. there was an increase in germination at the higher moisture tension. Table 16 presents a summary of the moisture and gibberellic acid effects on germination.

Table 16. Summary of the germination effects of four moisture tensions and four concentrations of gibberellic acid.

Osmotic tension in atmospheres	Gibberellic acid in ppm. 0	60	120	180	Means of tension effects
0	86.5	86.0	89.0	85.5	86.75
5	87.5	81.5	86.0	87.0	85.5
10	86.0	82.0	83.0	86.0	84.25
15	63.0	73.0	76.0	81.0	73.25
Means of gibberellic acid effect	80.75	80.62	83.5	84.87	

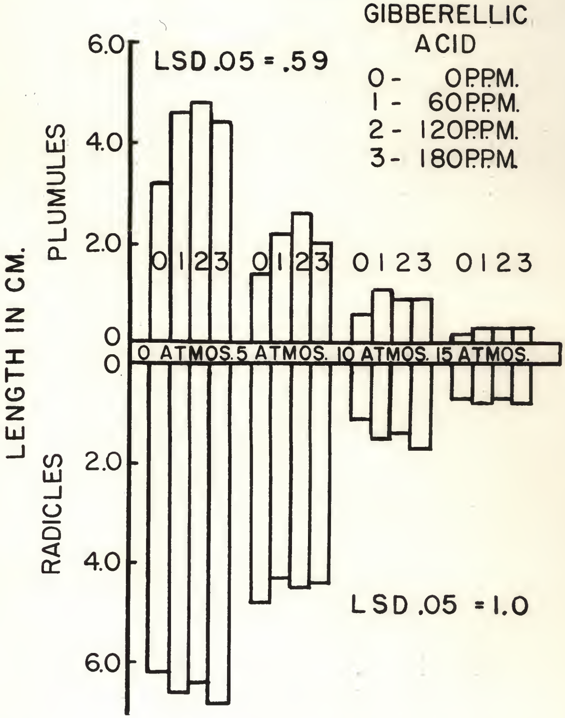

Figure 11. Average plumule and radicle lengths of variety RS 608 grain sorghum germinated at four moisture tensions and four gibberellic acid concentrations.

Seedling Growth. Seedling growth was measured by averaging the lengths of the plumules and radicles of five seedlings germinated at each treatment combination. The average lengths of the plumules and radicles for each treatment combination are shown in Figure 11. With the exception of the radicle lengths at 5 atmospheres of moisture tension, gibberellic acid increased growth of the seedlings over that in the moisture tension solutions alone. Growth of the seedlings decreased with increasing moisture tension, the differences in growth being significant at the 1 percent level for both radicles and plumules.

Analysis of variance of plumule and radicles growth as affected by four moisture tensions and four gibberellic acid concentrations is presented in Table 15.

The gibberellic acid treatments resulted in differences in plumule growth which were significant at the 1 percent level. The most notable of these differences occurred at 0 and 5 atmosphere moisture tensions. At both tensions plumule growth was increased by 60 and 120 ppm. gibberellic acid. However, plumule growth at 180 ppm. gibberellic acid was less than that attained by 120 ppm., suggesting that this concentration of gibberellic acid had a toxic affect on the seedlings. Plumule growth at 10 and 15 atmospheres moisture tension was increased by gibberellic acid but at 10 atmospheres the amount of growth at 120 ppm. gibberellic acid was no greater than that at 180 ppm. It would appear that either the effect of gibberellic acid was progressively lessened by increasing tension or that the toxicity level of seedling was lowered. Growth at 15 atmospheres obtained by gibberellic acid treatment was equal for all concentrations. Thus, there was a differential response of gibberellic acid to separate tensions, which would serve to explain the significant interaction

variance.

Although radicle lengths appeared to have been elongated in growth over the moisture tension checks by gibberellic acid treatment, these differences were not significant. At 5 atmospheres moisture tension growth of radicles with gibberellic acid treatment was actually less than the water checks.

The fact that gibberellic acid affected plumule growth to a greater degree than radicle growth is probably due to the relative amounts or concentrations of auxins or gibberellins that these organs can endure. The concentrations of auxin that favor plumule growth are evidently inhibitory to radicle growth. Since gibberellic acid is auxin-like in some of its actions, it is assumed the lesser radicle growth may be due to an inhibitory effect.

SUMMARY

Experiments were conducted in 1956 and 1960 to determine the germinability and seedling vigor of sorghum under varying conditions of moisture and temperature. Moisture tensions were produced by use of oven-dried soil remoistened to desired levels, and D-mannitol solutions. Three temperature ranges were obtained by placing the experimental material at different locations.

In the first experiment ten sorghum varieties were planted in soil with three moisture contents; field capacity (24.0 percent moisture), below permanent wilting coefficient (9.8 percent moisture), and an intermediate level (15.4 percent moisture). All treatments were

replicated four times in randomized blocks at temperatures of 60-70°F., 70-80°F., and 80-90°F.

To determine if variability of seed within a variety might be an important consideration in sorghum germination, ten lots of seed in each of five varieties were planted to soil in flats which were kept in the three temperature ranges mentioned above. Data were obtained on rate and extent of emergence.

The possibility of rating germinability at limited moisture conditions in the laboratory was tested by germinating four sorghum varieties in moisture (osmotic) tensions of 0, 5, 10, and 15 atmospheres created by mannitol solutions. There were four replications of each treatment combination in this randomized complete block experiment.

In a final experiment, RS 608 grain sorghum was germinated in four moisture tension solutions of 0, 5, 10, and 15 atmospheres which contained concentrations of 0, 60, 120, and 180 parts per million gibberellic acid. Possible influences of gibberellic acid on germination and vigor were the concern of this work.

In each experiment, daily counts were taken to determine rate of emergence or germination and total germination. In the last two experiments, seedling plumules and radicles were measured as an indication of seedling vigor.

This paper is a report of the results obtained from these experiments.

CONCLUSIONS

The results obtained from the preceeding experimental work lead to the following conclusions:

1. Lowering of temperatures below 80°F. resulted in an increased time of emergence for all varieties tested.

2. Temperatures below 80°F. reduced the total germination percentage for all varieties. Emergence (germination) at 60-70°F. was completely inhibited in one variety, and was so drastically reduced in all varieties as to probably result in failure to establish a stand under field conditions.

3. Reduction of available moisture, in soils and mannitol solutions, caused delay in time to germinate or emerge. Total germination was decreased as moisture tension of the germinating media increased. Germination was inhibited at tensions slightly below the wilting point.

4. High variability in germination response was found between seed lots within a variety, even when compared on a common basis of a laboratory germination test. This would indicate that seed work, especially in a comparison test between varieties, should be carefully qualified. The growing of one generation in a common environment for the seed source might be desirable for exacting work.

5. Increasing moisture tensions progressively reduced seedling growth. Radicle and plumule growth were affected almost to the same degree in reduction in length.

6. Selection of varieties with superior ability to germinate under limited moisture conditions by use of mannitol solutions would require

further study. Although varieties RS 608 and RS 610 were expected to exhibit greater germination at higher moisture tensions than the other varieties, germination of these two varieties was reduced to a greater extent than was the germination of Midland and KS 602.

7. Seedling growth may serve as an index of varietal vigor under limited moisture conditions as the differences between varieties was significant. RS 608 produced the longest radicles, but response to increasing moisture tensions was not greatly different from the other varieties. RS 610 showed the most uniform reduction, the radicle lengths shortening in almost a straight line relationship to increasing tensions.

8. Gibberellic acid treatment resulted in pronounced increases in germination percentage at the higher moisture tension, but little influence was noted at 0, 5, or 10 atmospheres tension. Further study on the use of increased concentrations of gibberellic acid may be desirable. Gibberellic acid treatment caused an increase in growth of plumules under limited moisture conditions, but increases in radicle lengths were not significant. Response of plumule growth to gibberellic acid varied at different moisture tensions.

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LITERATURE CITED

(1) Ayers, A. D.
Seed germination as affected by soil moisture and salinity. Agron. Jour. 1952. 44:82-84.

(2) Brown, A. J., and F. P. Worley.
Influence of temperature on the absorption of water by seed of Hordeum vulgare in relation to the temperature coefficient of chemical changes. Proc. Roy. Soc. London B. 1912. 85:546-553.

(3) Coffman, F. A.
The minimum temperature of germination of seeds. Jour. Amer. Soc. Agron. 1923. 15:257-270.

(4) Doneen, L. D., and J. H. MacGillivray.
Germination (emergence) of vegetable seed as affected by different soil moisture conditions. Plant Phys. 1943. 18:524-529.

(5) Dotzenko, A. D., and J. G. Dean.
Germination of six alfalfa varieties at three levels of osmotic pressure. Agron. Jour. 1959. 51:308-309.

(6) Edwards, T. I.
Temperature relations of seed germination. Quar. Rev. Biol. 1932. 7:428-443.

(7) Gingrich, J. R. and M. B. Russell.
A comparison of effects of soil moisture tension and osmotic stress on root growth. Soil Sci. 1957. 84:185-194.

(8) Haskell, G.
Effects of low temperatures on the germination of inbred lines of sweet corn. Science. 1948. 107(2771):150.

(9) Helmerick, R. H., and R. P. Pfeifer.
Differential varietal responses of winter wheat germination and early growth to controlled limited moisture conditions. Agron. Jour. 1954. 46:560-562.

(10) Hill, J. B., L. O. Overholts and H. W. Popp.
Botany. New York:McGraw-Hill, 1950. 710 p.

(11) Hunter, J. R. and A. E. Erickson.
Relation of seed germination to soil moisture tension. Agron. Jour. 1952. 44:107-109.

(12) Kasperbauer, M. J. and F. P. Gardner.
The effect of gibberellic acid and depth of seeding on emergence and growth of grain sorghum. Agron. Abs. 1959. 71.

(13) Marth, P. C., W. V. Audia and J. W. Mitchell.
Effects of gibberellic acid on growth and development of plants of various genera and species. Bot. Gaz. 1956. 118:106-111.

(14) Martin, J. H. and W. H. Leonard.
Principles of field crop production. New York:Macmillan, 1949. 1176 p.

(15) Martin, J. H., J. W. Taylor and R. W. Luekel.
Effect of soil temperature and depth of planting on the emergence and development of sorghum seedlings in the greenhouse. Agron. Jour. 1935. 27:660-665.

(16) Pauli, A. W. and E. L. Sorenson.
Vegetative and reproductive responses of dwarf alfalfa plants to gibberellic acid. Agron. Jour. Submitted for publication, Dec., 1960.

(17) Pauli, A. W. and F. C. Stickler.
Effects of seed treatment and foliar spray applications of gibberellic acid on grain sorghums. Agron. Abs. 1960. 60 p.

(18) Peters, R.
Moisture requirements of germinating seeds. Kans. Univ. Sci. Bull. 1920. 13:23-27.

(19) Powell, L. M. and R. P. Pfeifer.
The effect of controlled limited moisture on seedling growth of Cheyenne winter wheat selections. Agron. Jour. 1956. 48:555-557.

(20) Richards, L. A.
Diagnosis and improvement of saline and alkali soils. United States Department of Agriculture Agr. Handbook 60. 1954.

(21) Robbins, W. A. and R. H. Porter.
Germinability of sorghum and soybean seed exposed to low temperatures. Jour. Amer. Soc. Agron. 1946. 38(10):905-913.

(22) Rodger, J. B. A., G. G. Williams and R. L. Davis.
A rapid method for determining winter hardiness in alfalfa. Agron. Jour. 1957. 49:88-92.

(23) Ross, W. M. and H. H. Laude.
Growing sorghums in Kansas. Kansas Agricultural Experiment Station Circular 319. May, 1955.

(24) Rudolfs, W.
Influence of water and salt solution upon absorption and germination of seeds. Soil Sci. 1925. 20:15-37.

(25) Shull, C. A.
Temperature and moisture intake in seeds. Bot. Gaz. 1920. 62:361-390.

(26) Shull, C. A. and S. P. Shull.
Temperature coefficient of absorption in seeds of corn. Bot. Gaz. 1924. 77:262-279.

(27) Smika, D. E. and F. W. Smith.
Germination of wheat as affected by biuret contamination in urea. Soil Sci. 1957. 84:273-282.

(28) Snedecor, G. W.
Statistical methods. Ames, Iowa. The Iowa State College Press, 1956, 5th ed. 534 p.

(29) Stiles, I. E.
Relation of water to the germination of corn and cotton seeds. Plant Phys. 1948. 23:201-222.

(30) Stitt, R. E.
The effect of depth of planting on the germination of soybean varieties. Jour. Amer. Soc. Agron. 1934. 26(12)1001-1004.

(31) Stodola, F. H.
Source book on gibberellin. U.S.D.A. Northern Utilization Research and Development Div., Peoria, Ill. 1958.

(32) Stowe, B. B. and T. Yamaki.
The history and physiological action of the gibberellins. Annual Rev. of Plant Phys. 1957. 8:181-216.

(33) Swanson, A. F. and R. Hunter.
Effect of germination and seed size on sorghum stands. Jour. Amer. Soc. Agron. 1936. 28:997-1004.

(34) Thimann, K. V.
The physiology of growth in plant tissues. Amer. Sci. 1954. 42:589-606.

(35) Uhvits, R.
Effect of osmotic pressure on water absorption and germination of alfalfa seeds. Amer. Jour. Bot. 1946. 33:278-285.

(36) U. S. Department of Agriculture.
Crop Production. Crop Reporting Board, Wash., D. C. Nov., 1960.

(37) Veerhoff, O.
Time and temperature relations of germinating flax. Amer. Jour. Bot. 1940. 27(4):225-231.

(38) Wiggans, S. C. and F. P. Gardner.
Effectiveness of various solutions for simulating drouth conditions as measured by germination and seedling growth. Agron. Jour. 1959. 51:315-317.

(39) Wilson, H. K.
Wheat, soybean, and oat germination studies with particular reference to temperature relationships. Jour. Amer. Soc. Agron. 1928. 20(6):599-619.

SORGHUM SEED GERMINATION AS AFFECTED BY MOISTURE AND TEMPERATURE

by

WILBUR FELL EVANS

B. S., Pennsylvania State University, 1955

AN ABSTRACT OF A THESIS

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Sorghums have assumed an ever increasing economic importance since their introduction into the United States.

However, successful establishment of a crop stand has continued to be a major problem with the crop. Soil moisture and temperature are two factors which evidently exert a great influence in stand establishment.

This study was conducted to determine if certain varieties exhibited superior ability to germinate and emerge under different moisture and temperature conditions. It was also attempted to determine if variability of seed lots within a variety was a factor in germination work. The possibility of testing seedling vigor under laboratory conditions was explored, as was the effect of gibberellic acid on sorghum germination and seedling growth under limited moisture conditions.

Moisture tensions were created by use of oven dried soil remoistened to three desired moisture levels and by use of mannitol solutions. The first two experiments were conducted using temperature ranges of 60-70°F., 70-80°F., and 80-90°F. In the final two experiments, using mannitol solutions, temperature was not a factor. Randomized block designs were used in all experiments.

Lowering of temperatures resulted in increased time for total emergence and reduced total emergence for all varieties tested. Temperatures of 60-70°F. completely inhibited emergence of one variety and emergence of all varieties was reduced as to probably result in failure to establish a crop stand.

Individual seed lots of five grain sorghum varieties showed high variability in emergence when germinated at the three temperature ranges.

Increasing moisture tensions resulted in delay in time to germinate or emerge and reduced total germination and emergence. No germination was obtained from a soil moisture percentage slightly below the permanent wilting point.

No varieties could be selected as superior in ability to germinate or emerge at the various moisture levels and temperatures as the variety responses to the treatment combinations were somewhat varied.

Increasing moisture tensions progressively reduced plumule and radicle lengths. Selection of varieties with ability to grow under limited moisture conditions by use of mannitol solutions would require further study as responses in growth in mannitol solutions were not in agreement with the results expected from field observations.

Gibberellic acid treatment increased rate of germination and at high concentrations increased total germination to a small degree at moisture tensions up to 15 atmospheres. Radicle and plumule growth was increased by gibberellic acid treatment at all moisture tensions. However, plumule growth at 180 ppm. gibberellic acid was less than the growth attained at 120 ppm. indicating the higher concentration produced a toxic effect.